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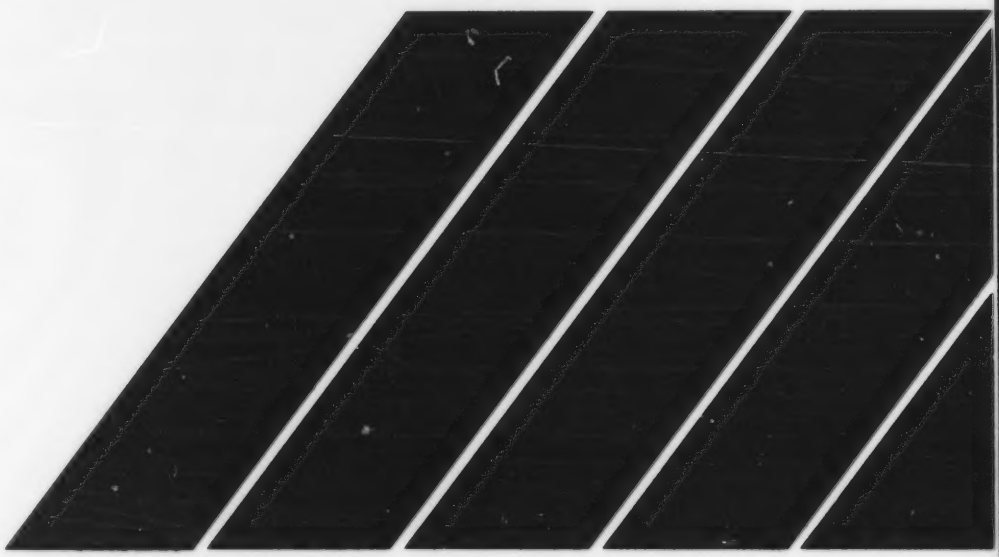
MONITORED PERFORMANCE OF THE SOLAR-HEATED VENTILATION SYSTEM AT MCDONNELL-DOUGLAS CANADA



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MONITORED PERFORMANCE OF THE SOLAR-HEATED VENTILATION SYSTEM AT MCDONNELL-DOUGLAS CANADA

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
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RÉSUMÉ

En ce qui a trait au chauffage solaire, l'un des meilleurs domaines d'application est le préchauffage de l'air de ventilation d'un immeuble. Parce que l'air d'admission se trouve à la température ambiante, le rendement du capteur atteint presque un niveau optimal, avec un minimum de pertes de chaleur vers l'extérieur. La surveillance détaillée du système de ventilation avec préchauffage solaire utilisé aux installations d'Oakville de la Fc d Motor Company a permis de confirmer le niveau élevé de rendement de ces systèmes (McClenahan et Carpenter, 1989).

Afin de diminuer les coûts des systèmes de ventilation avec préchauffage solaire, la société Conserval Engineering Inc. a mis au point un modèle non vitré de son capteur. Dans ce système, la façade sud de immeuble est peinte d'une couleur foncée et une prise d'air est installée à la partie supérieure du mur (voir la figure 1.1). Le rayonnement solaire incident réchauffe l'air près du mur; cet air monte le long du mur par convection naturelle et est aspiré dans l'immeuble par la prise d'air. Parce que l'air chauffé par le soleil est habituellement plus froid que l'air près du plafond, cet air chaud a tendance à déstratifier l'air de l'immeuble. Le rayonnement solaire absorbé par le mur sert aussi à réduire les pertes de chaleur résultat des effets de l'air ambiant.

La mise à l'essai d'une section du système non vitré, par le Centre national d'essais d'équipements solaires, a permis de constater que ce système peut atteindre des rendements de 50 % lorsque la vitesse du vent est basse et la circulation de l'air est élevée. Toutefois, il faudra vérifier le rendement sur place d'un système complet afin de pouvoir déterminer le véritable rendement du système.

Le présent rapport donne les résultats de l'étude du rendement d'un système de ventilation faisant usage d'un capteur non vitré pour le préchauffage solaire, qui a été installé à l'usine McDonnell-Douglas de Toronto. Cette étude avait pour objectifs de quantifier les économies d'énergie du système et de déterminer les améliorations possibles de la conception du système.

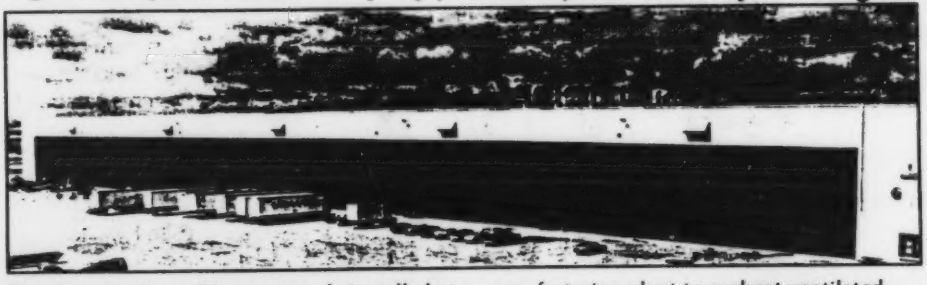
1. INTRODUCTION

One of the best applications for solar heating is the preheating of building ventilation air. Because the inlet air is at ambient temperature, the collector operates at close to its maximum efficiency with little heat loss to the outdoors. Detailed monitoring of the solar preheated ventilation system at the Ford Motor Company in Oakville confirmed the high performance of these systems [McClenahan and Carpenter, 1989].

To reduce the cost of solar preheated ventilation systems, Conserval Engineering Inc. developed an unglazed version of their collector. In this system, the south wall of the building is painted a dark colour and an air intake is installed at the top of the wall (see Figure 1.1). Incident solar radiation warms the air near the wall, which rises up the wall by natural convection to be pulled into the building by the intake. Because the solar heated air is generally cooler than the air at ceiling level, the solar heated air tends to destratify the building air. Solar radiation absorbed by the wall also reduces the wall heat loss because of the sol-air effect.

Testing of a section of the unglazed system at the National Solar Test Facility showed that the system can have efficiencies of up to 50% under conditions of low wind speed and high air flow. There is, however, a need to determine the in-situ performance of a full scale system to determine the true system performance.

This report presents the results of performance monitoring of an unglazed solar-preheated ventilation system at the McDonnell-Douglas plant in Toronto. The objectives of the monitoring were to quantify the energy savings of the system and to identify any potential improvements in system design.



This large "solar wall" was recently installed at a manufacturing plant to preheat ventilated air. (Photo courtesy of Conserval Systems, Inc.)

Figure 1.1

2. SYSTEM DESCRIPTION

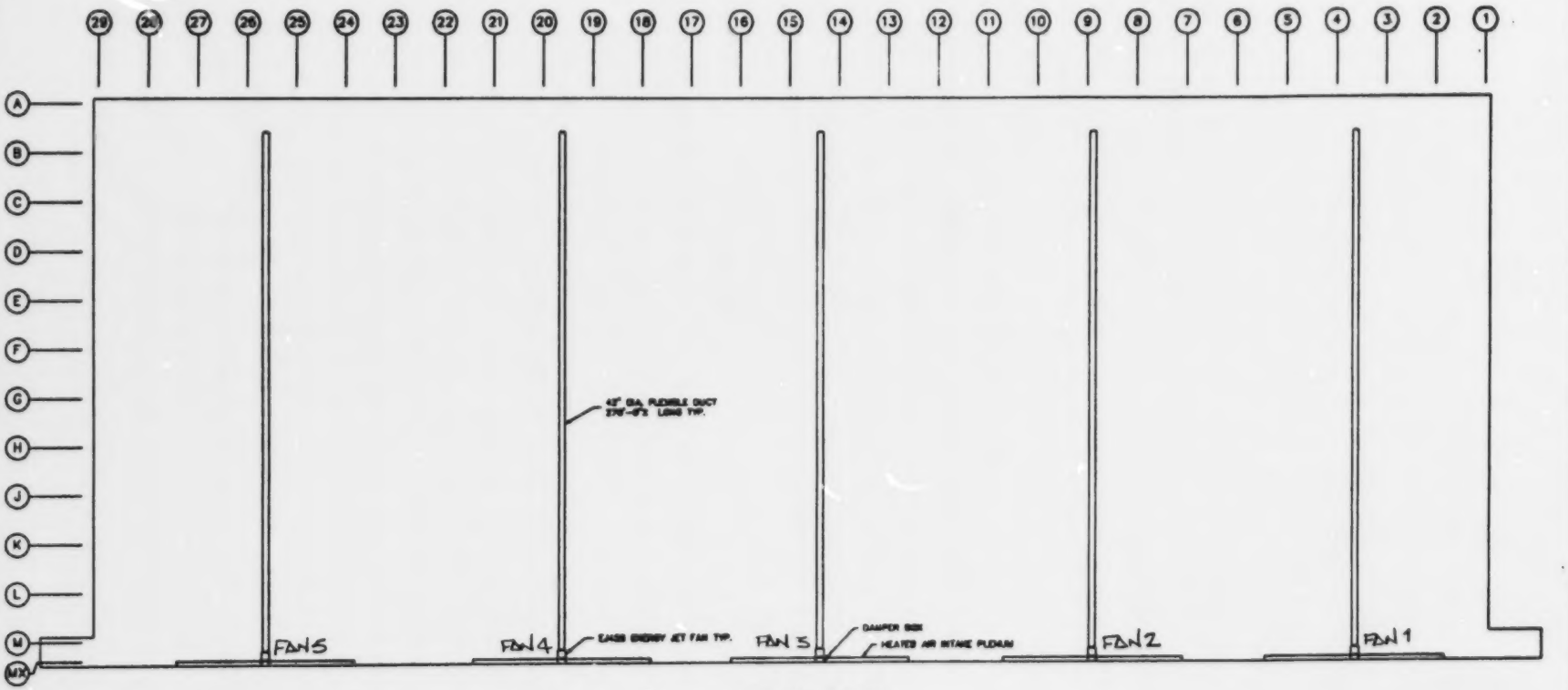
2.1 The Building and The Solar Heating System

The McDonnell-Douglas plant in Toronto produces assembled aircraft wings: a clean working environment and precise control of temperature are required to ensure consistent product quality. The original HVAC system did not provide any mechanical ventilation (supply or exhaust). Fresh air entered by natural infiltration through cracks in the building shell (usually near floor level). McDonnell-Douglas decided to install a make-up air system to improve air quality. The two alternatives investigated were roof-top gas-fired make-up air units and the Conserval Solarwall. The Conserval system was chosen because of its low cost and energy savings potential.

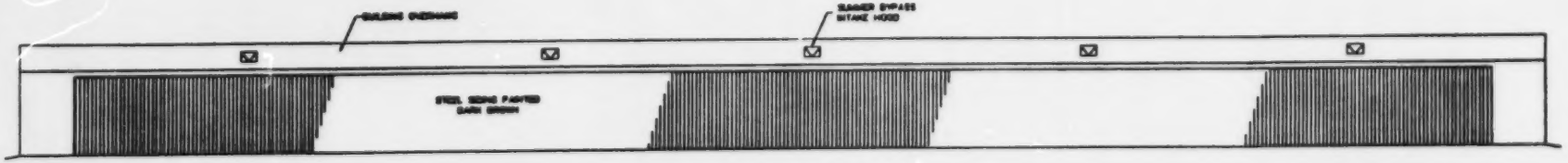
The McDonnell-Douglas plant is a large airplane hangar (see Figure 2.1) approximately 250 metres by 100 metres by 18 metres high. Hangar doors make up most of the south side of the plant. Most of the doors have been closed permanently, only the end section is operable to permit movement of materials. The building is heated by a series of ceiling-mounted steam unit heaters.

An unglazed Solarwall system was installed at the plant in early 1989. The hangar doors, covering an area of 2677 square metres and facing 52° east of true south were painted dark brown. Five air handlers and ducting systems were installed along the length of the wall. Intake plenums are located in the canopy overhanging the hangar wall. To keep construction costs down, the intake plenums did not run the full length of the hangar wall. Each air handling system consisted of eight intake plenums each 300 mm wide by 1200 mm long. These plenums were evenly spaced over 26 metres of wall length. As can be seen in Figure 2.1 there is a section of wall between each handling system that is not serviced by the air handlers (approximately 40% of the area). Flexible air distribution ducts are connected to each blower and run almost the full width of the building.

The air handler uses a recirculation damper to control the outlet temperature of the air to avoid any discomfort problems caused by blowing cold air into the building. If the air entering the building is cold (typically below 0 degrees Celsius), recirculated air is at the maximum and fresh air at the minimum setting. If the air entering the building is warm (typically above 10 degrees Celsius), the recirculation damper is fully closed. In summer (i.e., when the outdoor temperature is typically above 16 degrees Celsius), a bypass damper on the front of the canopy opens to reduce the quantity of solar-heated air entering the building. The setpoints for the operation of the dampers were periodically adjusted by Conserval and McDonnell-Douglas staff during the monitoring period to maximize thermal comfort in the



PLAN VIEW



SOUTH ELEVATION

SOUTH

Figure 2.1

CONSERVAL ENGINEERING INC.

SOLARWALL
McDONNELL DOUGLAS
TORONTO, ONTARIO

SOUTH ELEVATION & PLAN
13/3/89
NTS
MDX-2

building. These adjustments resulted in less outdoor air being brought in and more air being recirculated during the winter. The hangar wall was initially insulated with a sprayed-on fibrous insulation. This insulation was removed during the last week of December and replaced with sprayed-on urethane insulation.

2.2 The Monitoring System

The purpose of the monitoring system is to provide sufficient data to determine the solar heat collected and savings due to destratification. Hourly values of the data required to determine these energy savings were collected by a PC-based data acquisition system. The monitoring software for data acquisition and storage was written at Queen's University. The data points are scanned continuously and stored on the computer every hour.

A list of the monitoring points are given in Table 1 and shown in Figure 2.2. Only the middle air handling system (#3) was monitored in detail; it was assumed that total system savings would be five times the monitored value. The inlet air temperatures in unit 1 and 5 were monitored to serve as a check on this assumption. South wall temperatures and boundary air flow were also monitored to get an indication of the air movement up the wall. Several temperatures were monitored inside the building to assess the degree of temperature stratification.

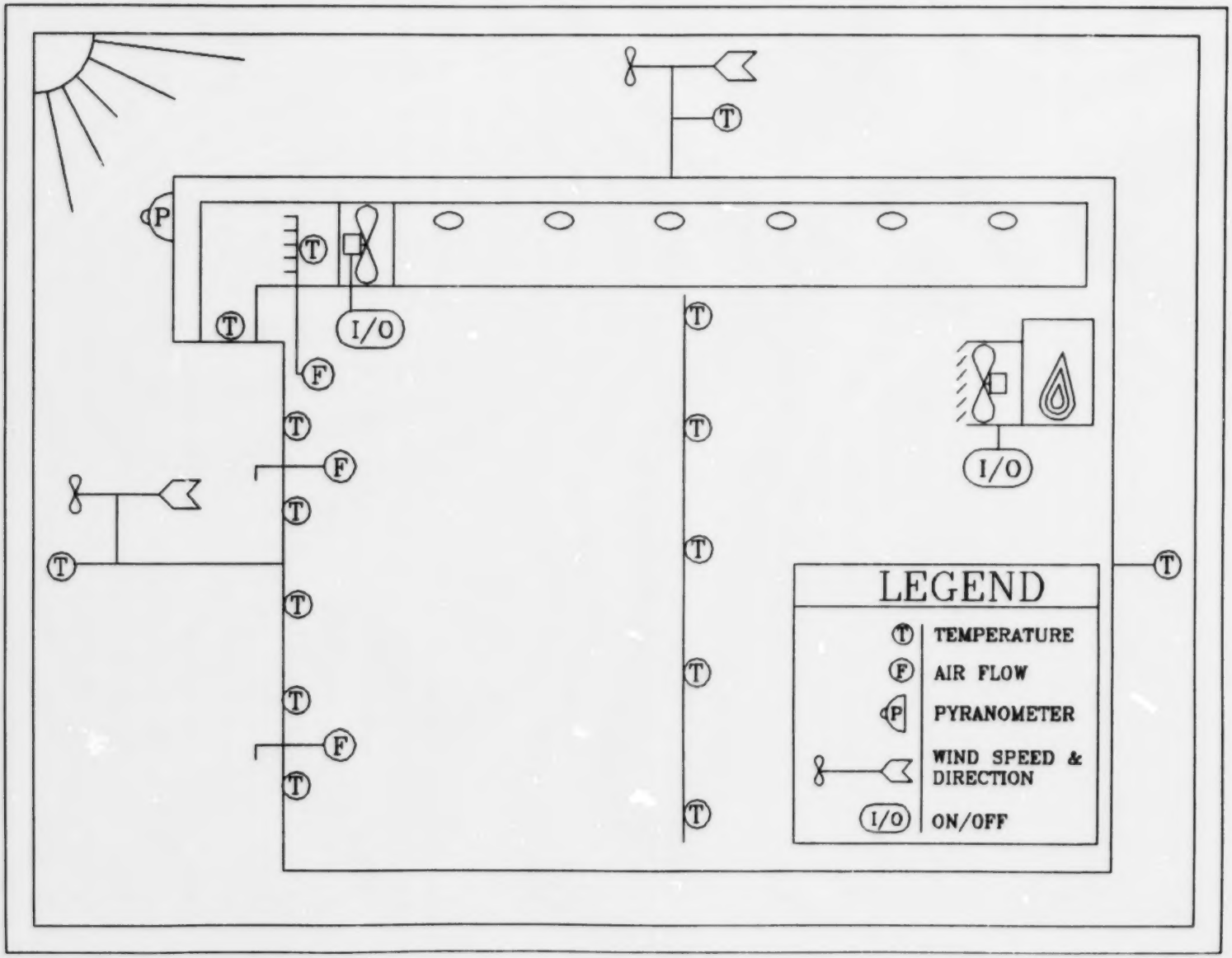
The system was installed at McDonnell-Douglas in the fall of 1989. The monitoring system was commissioned in November and December 1989. It was found that the pitot tubes installed to measure duct air flow were not giving reliable readings because of the high turbulence in the duct. The pitot tubes were replaced with flow-averaging grids. The hot wire anemometer measuring bottom of the wall boundary flow appeared to be giving false readings. Solving this problem would have required returning the part to the factory. The computer clock battery failed in early December, causing the computer to lose time during power outages. The battery was replaced in late December, but failed again in early March. The battery was replaced mid-March but again the same symptoms appeared. There appears to be a computer hardware problem. To use the data, it was necessary to manually correct the time after power failures. The status switch on the steam heater failed in early December. The switch was replaced, but the wire was accidentally cut in late December and repaired in early January. It was later determined that the heaters are operated manually: therefore, the operation of the monitored heater would not be representative of building heating requirements.

Analysis of the first data collected in late November showed that the temperature of the air entering

Table 1. Monitoring Points at McDonnell-Douglas

Number	Measurement	Location	Device
1	Solar Radiation	South Wall	Pyranometer
2	Roof Air Temperature	Roof	RTD
3	South Side Temperature	Out from wall	RTD
4	North Side Temperature	North Side	RTD
5	Inlet Air Temp.	Duct Inlet 1	Thermocouple
6	Inlet Air Temp.	Duct Inlet 2	Thermocouple
7	Inlet Air Temp.	Duct Inlet 3	Thermocouple
8	Inlet Air Temp.	Duct Inlet 4	Thermocouple
9	South Wall Temp.	Top of Wall	Thermocouple
10	South Wall Temp.	Mid-Top	Thermocouple
11	South Wall Temp.	Mid-wall	Thermocouple
12	South Wall Temp.	Mid-Bottom	Thermocouple
13	South Wall Temp.	Bottom of Wall	Thermocouple
14	Building Temp.	Ceiling	Thermocouple
15	Building Temp.	Mid-Ceiling	Thermocouple
16	Building Temp.	Mid-Level	Thermocouple
17	Building Temp.	Mid-Floor	Thermocouple
18	Building Temp.	Floor	Thermocouple
19	Fan 1 Inlet Temp.	Duct	RTD
20	Fan 3 Inlet Temp.	East Duct	RTD
21	Fan 3 Inlet Temp.	West Duct	RTD
22	Fan 5 Inlet Temp.	Duct	RTD
23	Roof Wind Speed	Roof	Anemometer
24	Roof Wind Direction	Roof	Vane
25	Wall Wind Speed	South Wall	Anemometer
26	Wall Wind Direction	South Wall	Vane
27	Boundary Layer Flow	Top South Wall	Anemometer
28	Boundary Layer Flow	Btm South Wall	Anemometer
29	Fan 3 East Flow	East Duct	Flow Grid
30	Fan 3 West Flow	West Duct	Flow Grid
31	Steam Heater Status	Ceiling Heater	Current Switch
32	Fan 3 Status	Fan 3	Current Switch

Figure 2.2 McDONNELL DOUGLAS SOLARWALL MONITORING SCHEMATIC



the fan was approximately 5 Celsius degrees above the ambient temperature in the middle of the night (see Figure 3.5). Because the south wall temperatures were close to ambient, it was concluded that the system air was being heated by other than solar energy. This heating could be caused by heat gains from the indoor air through the duct walls or from air leaking into the duct upstream of the temperature sensor. To quantify these effects, temperature sensors were installed in the intake plenums in late December.

Despite the problems described above, the monitoring system operated reliably over the monitoring period. Valid data were obtained for January and February, 1990. Data from mid-March to May is available, although manual time adjustments will be necessary to use this data, to correct for clock problems.

3. MONITORING RESULTS

3.1 Weather Conditions

The performance of the unglazed Solarwall is more dependent on wind speed and ambient temperature than are glazed systems. Therefore, it is necessary to study how these parameters vary over the monitoring period.

One concern of the unglazed Solarwall design is the wind speed over the Solarwall: a high wind may make the system ineffective. A wind anemometer was mounted 5.2 metres above the building roof to measure free-stream velocity, which is representative of airport-measured wind speed. The second anemometer was mounted on the south wall at mid-height, two metres away from the wall. Figure 3.1 shows the hourly wind speeds measured by the two anemometers averaged over 50 days in January and February. The wind speed at the wall averages 2.1 metres/sec less than half of the 4.6 metres/sec measured on the roof. The average wind speed measured at the Toronto airport (less than 4 kilometres away) was 5.0 metres/sec, very close to the rooftop reading.

Figures 3.2 and 3.3 show wind profiles on two representative days when the winds were generally from the north-west and south-east respectively. The hollow symbols show the wind direction and speed (distance from the centre) for the roof-mounted anemometer, and the solid symbols show the corresponding values for the wall-mounted anemometer. The monitored data indicate that the wind at the wall is always blowing parallel to it, regardless of the free-stream wind direction. The figures also show that the velocity of the wind at the wall is consistently lower than the free-stream velocity.

Conventional ventilation make-up air systems use roof-top air for ventilating the building. The Solarwall, on the other hand, takes its ventilation air from the south side of the building. This in itself is an energy benefit, because solar effects cause the air on the south side to be warmer than roof-top air. Figure 3.4 shows the average air temperature for January and February. The south-side air is two Celsius degrees warmer than the roof-top air at night, and as high as 3.5 Celsius degrees during the day. It is possible, however, that some of the temperature difference during the day is caused by solar-heated air from the Solarwall.

Free Air and Solar Wall Wind Speed

McDonnell Douglas Solar Wall

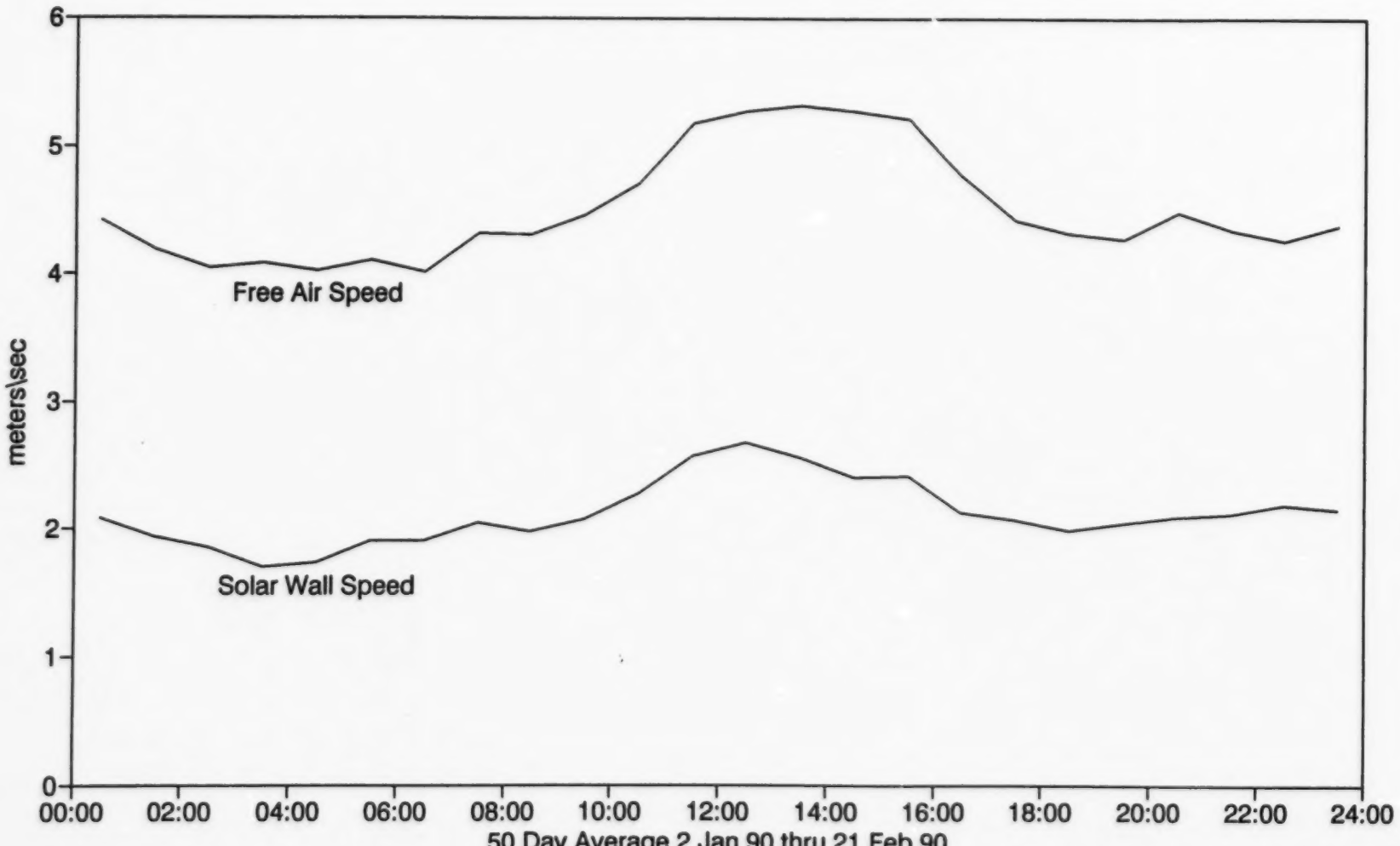


Figure 3.1

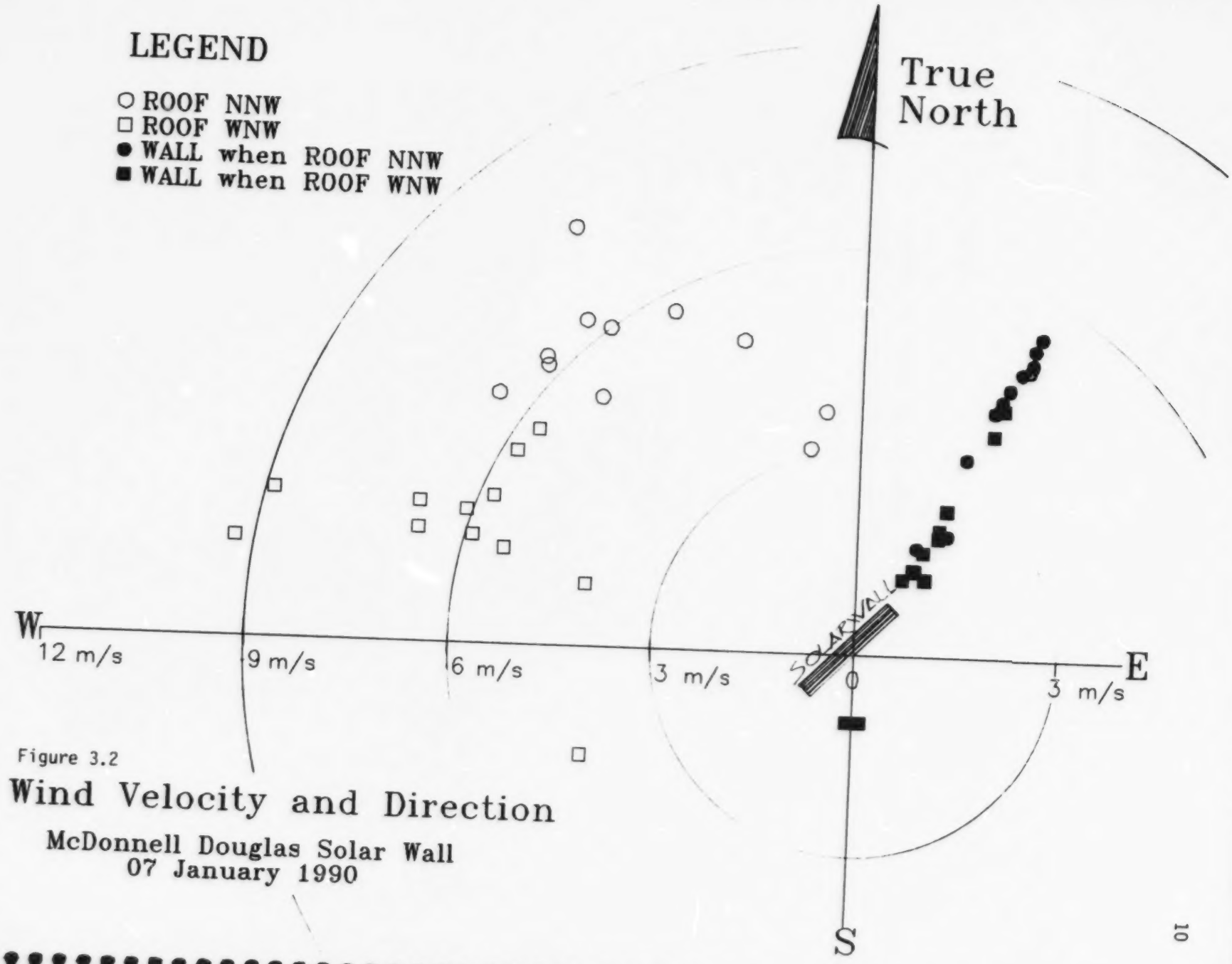


Figure 3.2

Wind Velocity and Direction

McDonnell Douglas Solar Wall
07 January 1990

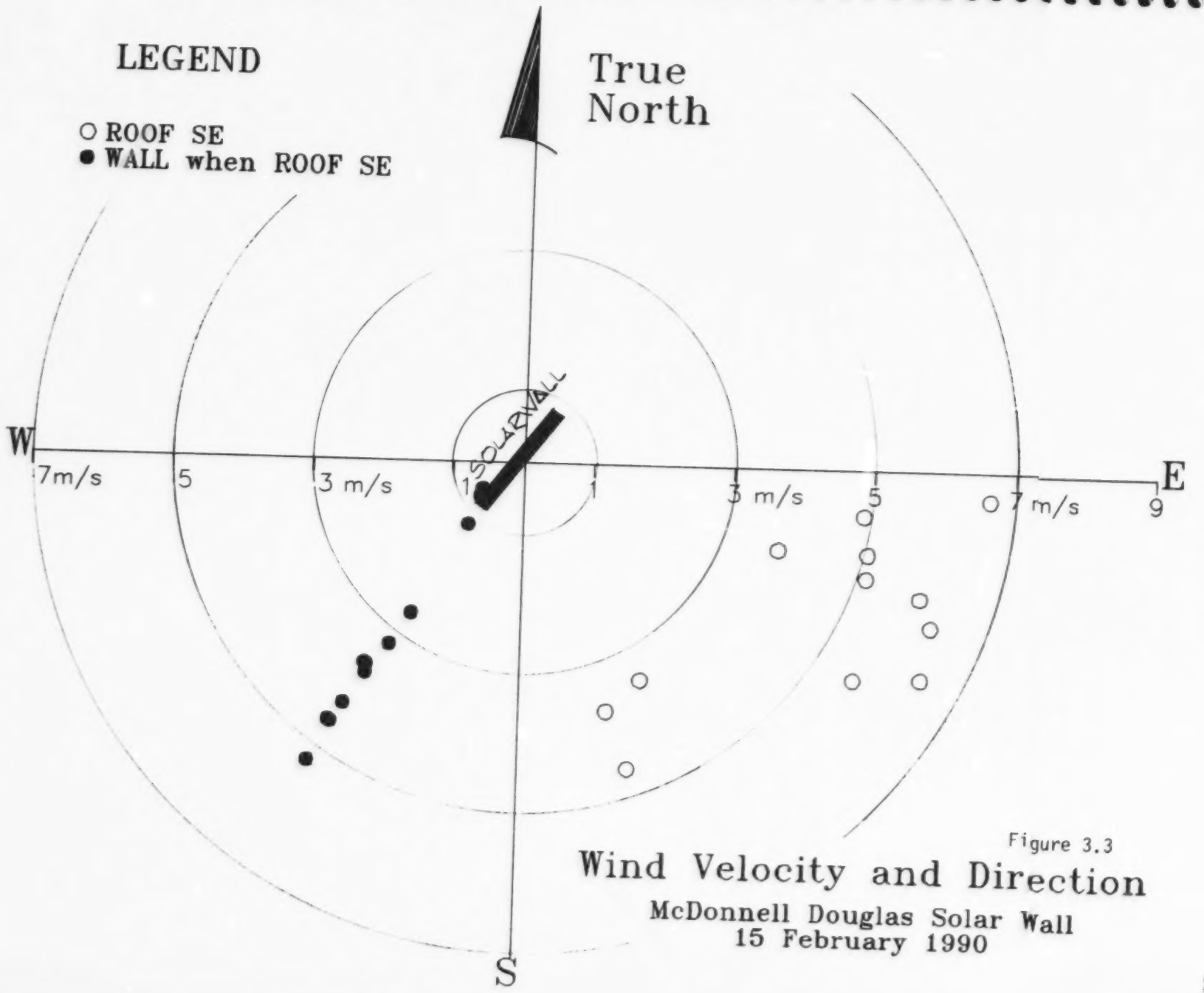


Figure 3.3

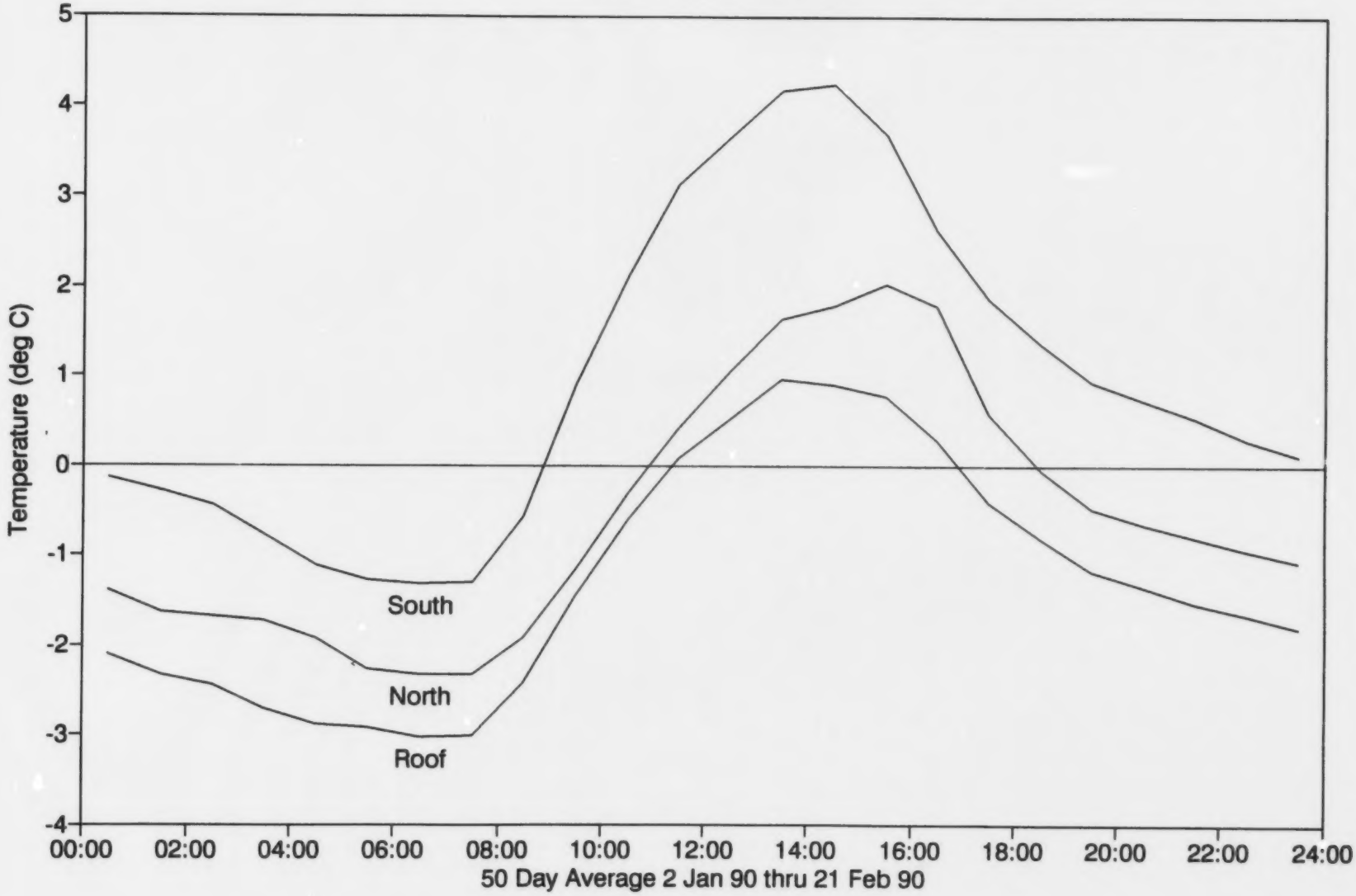
Wind Velocity and Direction

McDonnell Douglas Solar Wall
15 February 1990

Figure 3.4

Outdoor Temperatures at 3 Locations

McDonnell Douglas Solar Wall



3.2 Solarwall Heat Delivered

As discussed in Section 2.2, it was necessary to add temperature sensors at the duct inlet grilles to obtain an accurate reading of the solar-heated air temperature. Figure 3.5 shows the hourly values of air temperatures in the system averaged over January and February. Although the air temperature at the duct inlet is (on average) 2°C cooler than at the air handler fan (duct outlet), the inlet air is still 5 to 6°C warmer than either the ambient air or the top portion of the south wall during the night. This suggests that a source other than the Solarwall is providing heat to the system.

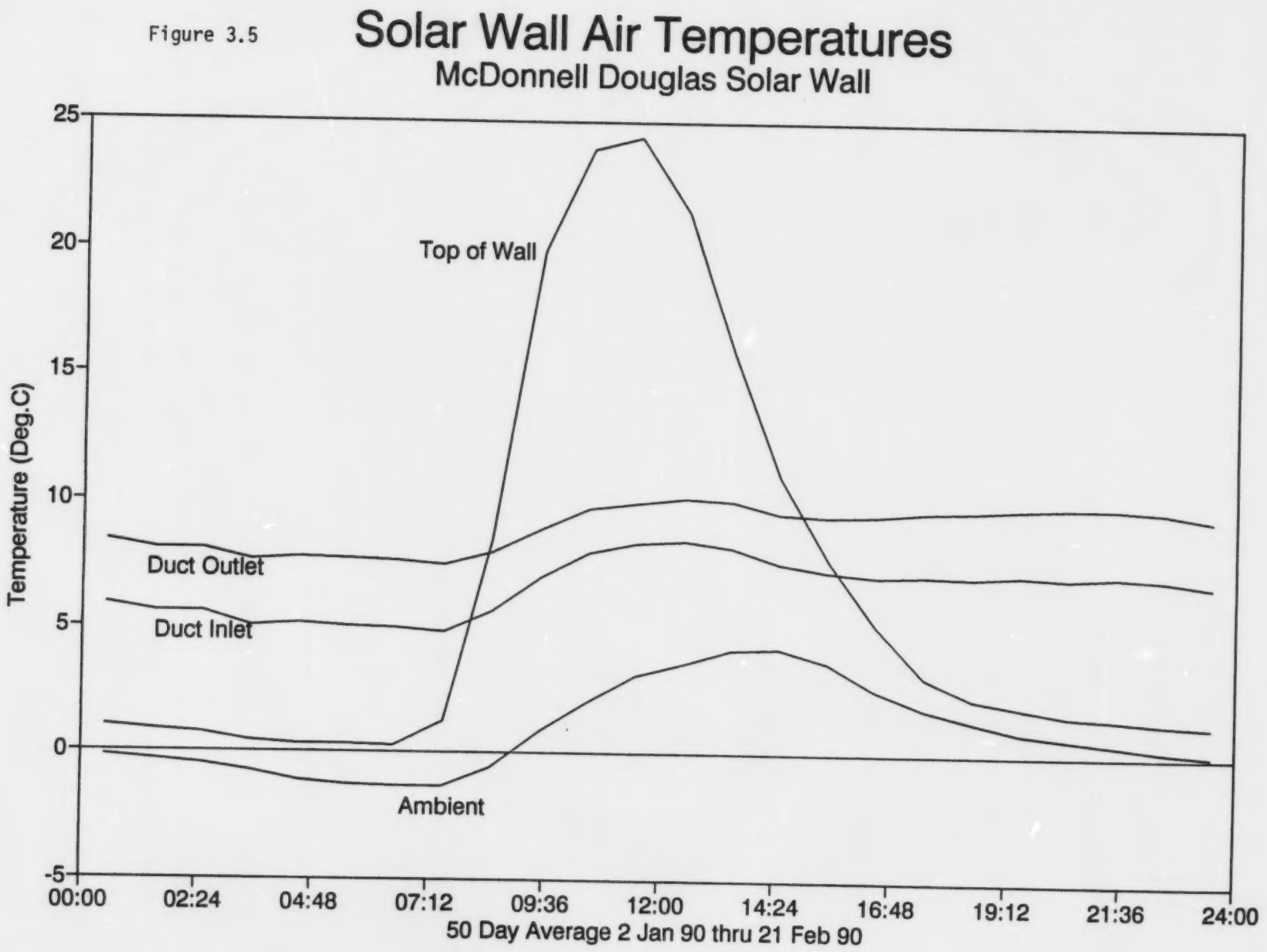
The building has no mechanical exhaust. It was suspected that the Solarwall make-up air system was pressurizing the building, causing warm building air to be forced out through any openings in the building shell. If these openings are physically close to the Solarwall intake grilles, warm building exhaust air could be drawn back into the building.

A site visit was made in first week of February. It was found that warm air was being blown out of the building in three locations in the vicinity of the intake grilles (see Figure 3.6): the top of the hangar door, the canopy-wall interface and around the intake plenum. These crack locations ran the full length of the hangar wall. It would be extremely difficult to seal these openings. Because of the turbulent flow near the intake plenum, it was not possible to measure the amount of air that leaked out of the building and was drawn back in.

An attempt was made to calculate the amount of exhaust air re-entering the building. The analysis was divided into two parts: day and night. Over the night it was assumed that the maximum intake temperature (if there were no exhaust air recirculation) would be equal to the surface temperature at the top of the wall. The lowest inlet air temperature should be the ambient temperature on the south side of the building. Within these limits, it was calculated that, on average, between 20 and 25% of the intake air flow was actually recirculated building air.

A different approach had to be used to estimate daytime air leakage because of the solar gains on the wall. If the same percentage of air leakage were applied to the daytime flow, a negative solar heat collection would be calculated--which is, of course, an unrealistic result. Two changes occur in building operation during the day. First, the Solarwall control strategy results in more air entering the building during the day (because the ambient temperature is usually higher during the day, see Figure 3.7). Thus, while the quantity of air leakage could be the same the percentage would be lower. Second,

Figure 3.5


Solar Wall Air Temperatures
McDonnell Douglas Solar Wall
25
20
15
10
5
0
-5
Temperature (Deg.C)
Top of Wall
Duct Outlet
Duct Inlet
Ambient
00:00
02:24
04:48
07:12
09:36
12:00
14:24
16:48
19:12
21:36
24:00
50 Day Average 2 Jan 90 thru 21 Feb 90

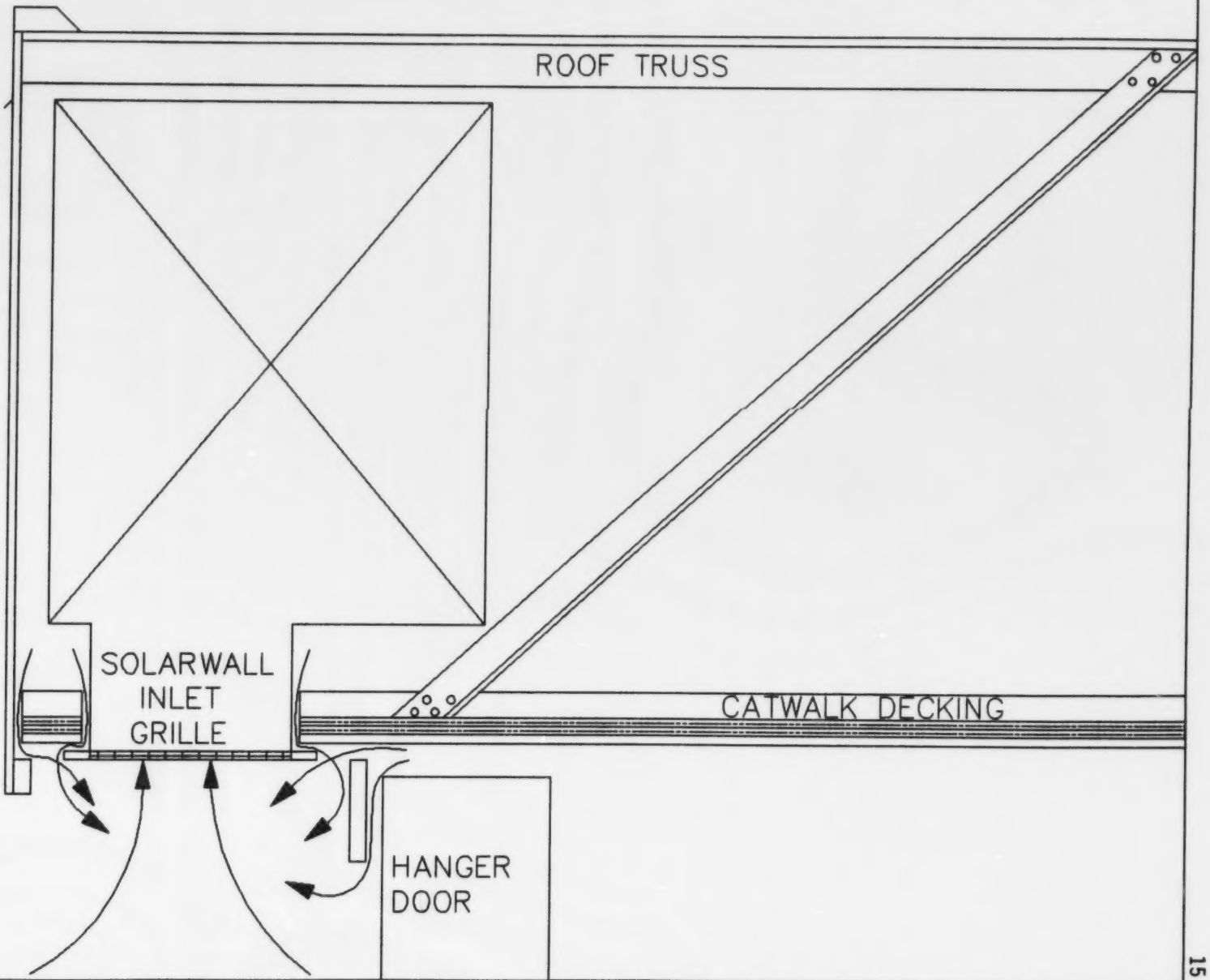


Figure 3.6

ENERMODAL ENGINEERING	McDONNELL DOUGLAS SOLARWALL LEAKAGE AREAS NEAR INLET GRILLES	date: JUNE 90	dr by: JK
		scale: NTS	dr no:

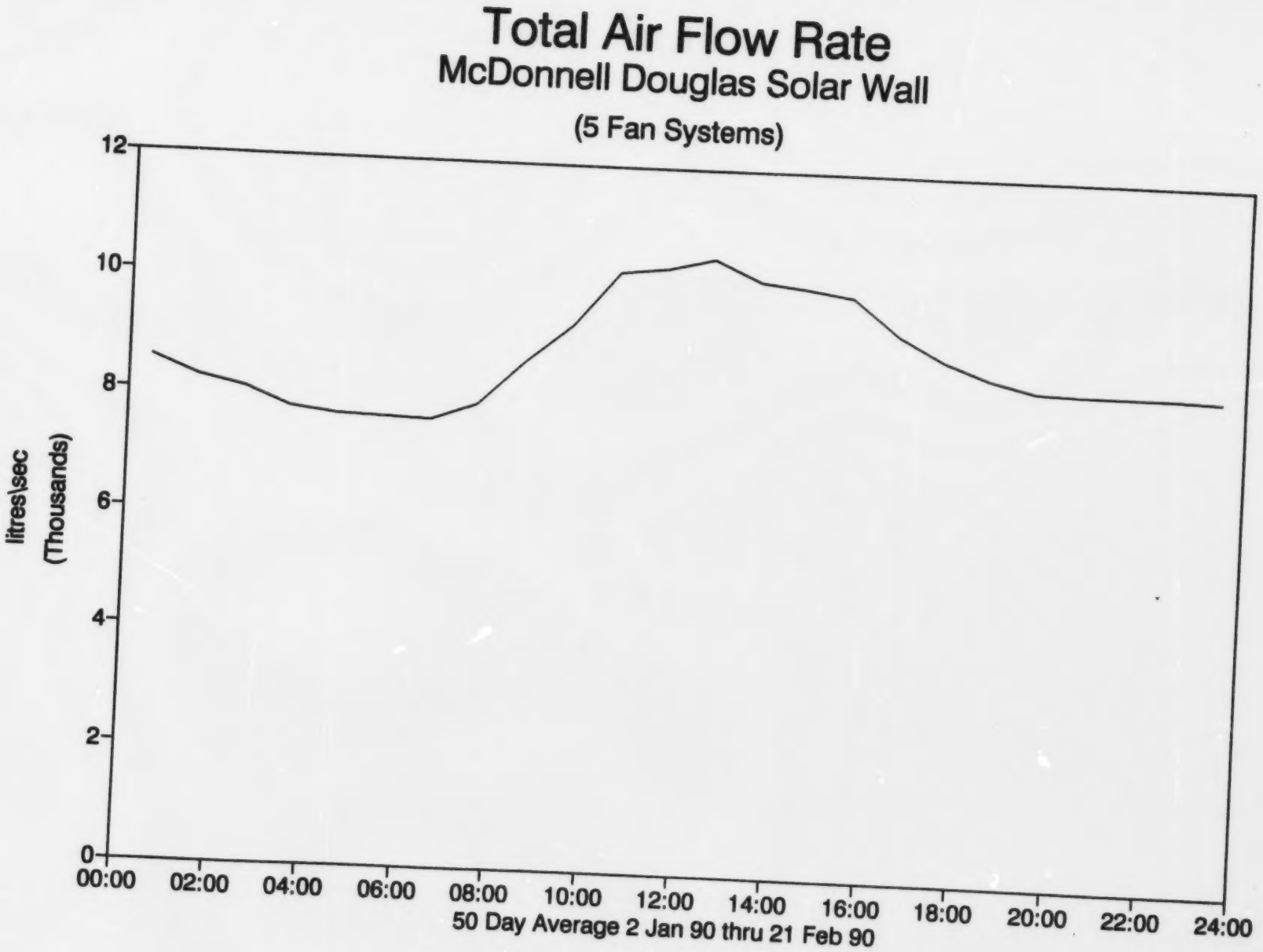

Total Air Flow Rate
McDonnell Douglas Solar Wall
(5 Fan Systems)
litres\sec
(Thousands)
12
10
8
6
4
2
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
24:00
50 Day Average 2 Jan 90 thru 21 Feb 90

Figure 3.7

loading doors, windows and entrances are more likely to be open during the day, providing an easier path for air leakage. Examining a few heavily overcast days, it was found that a recirculation rate of between 6 and 12 percent gave similar savings as the nighttime monitoring.

It is unlikely that the amount of air recirculation found at McDonnell-Douglas would be found in other buildings. Most industrial buildings are under a negative pressure because of the large quantity of mechanical exhaust air. In addition, most other buildings do not have hangar doors or the wall-roof interface construction found at McDonnell-Douglas. The air leakage at the top of the wall tends to force any solar-heated air rising up the wall out and away from the inlet plenums. For these reasons, it is felt that the Solarwall system at McDonnell-Douglas is not representative of a "typical" Solarwall installation. Nevertheless, an attempt was made to quantify the energy savings of the McDonnell-Douglas system.

Figure 3.8 shows the 50-day average heat delivered for the entire Solarwall. The heat delivery is made up of three components: ambient temperature gains, reduced wall heat loss and air heating. The ambient temperature gain is the energy saved by using air from the south-side of the building as opposed to using roof-top air (as is done by conventional make-up air units). The air heating is the energy gain of the south-side air as it rises up the wall to the inlet plenum. The minimum and maximum values represent the uncertainty in the quantity of recirculated air. During the night the wall is warmer than the air because of heat losses from the building. As was discussed in Section 3.1, some of the temperature increase of the south-side air over the roof-top air may be due to the Solarwall. Thus, the split between ambient gains and solar heat collection should be considered an approximation.

The reduction in wall heat loss is due to solar energy being absorbed on the wall and raising the wall temperature, thereby reducing the temperature difference and heat loss across the wall. This is often called the "sol-air effect". The reduction in wall heat loss was calculated with the equation:

$$Q_{sol\text{-}air} = (T_{wall1} - T_{wall2}) * A / R$$

where T_{wall1} is the monitored wall temperature

T_{wall2} is the wall temperature if the walls were in its original state

$= T_o + (T_{wall1} - T_o)\ a_y / a_1$

Total Energy Delivered

McDonnell Douglas Solar Wall

(5 Fan Systems)

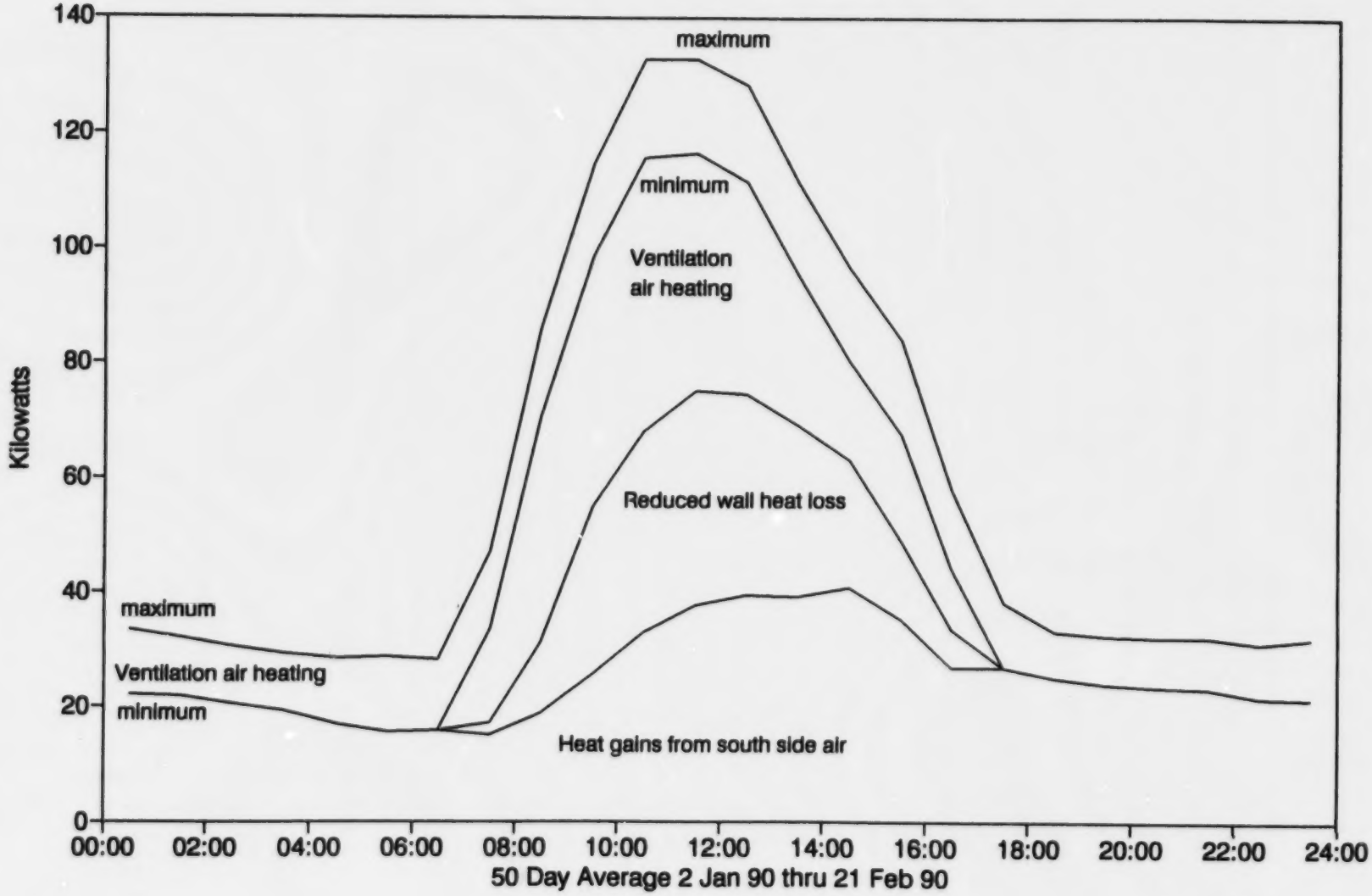


Figure 3.8

R value of the wall (estimated to be RSI 1.0)

a_2 solar absorptivity of the original wall (0.35)

a_1 solar absorptivity of the dark brown wall (0.85)

The daily average energy delivered by the system is between 1132 and 1433 kWhrs of which 610 kWhrs is due to ambient temperature gains, 233 kWhrs due to reduced wall heat loss and between 289 and 590 kWhrs due to air heating. The solar heat collection efficiency (based on savings from wall heat loss and air heating) is between 8.9 and 11.6 percent.

3.3 Destratification Savings

The air entering the building from the Solarwall system is usually cooler than the air at the ceiling, and air tends to destratify the building air as it falls to floor level. Reducing the ceiling air temperature lowers ceiling and upper wall heat loss (and exhaust air temperature, if the exhaust fans are at ceiling level). A comparison of the temperature stratification was made between a day when one of the Solarwall air handling fans was off and a day when it was on. (Normally, the fan is on all the time but on one day the fan had inadvertently been shut off.) When the fan was off, the ceiling-to-floor temperature difference averaged 2.5 Celsius degrees. The temperature difference with the fan on was a negative 0.5 Celsius degrees--a reduction of 3 Celsius degrees. The operation of the central blower was the only one monitored; the status of the other four units is not known. Thus, it is probable that the temperature stratification savings is underestimated.

3.4 Computer-Predicted Energy Savings

It is important to be able to predict in advance of construction the expected energy savings of a system. Computer predictions of energy savings help in system sizing and determination of system economics. The SIMAIR computer program was used successfully in the analysis of the glazed solar heating system at the Ford plant in Oakville [McClenahan and Carpenter, 1989].

Several difficulties arose in attempting to use this program for the McDonnell-Douglas system. First, SIMAIR uses the standard collector efficiency curve (Frta and FrUl) to predict collector performance. It is not clear whether this model is applicable to an unglazed Solarwall. For example, with the standard collector model, doubling the collector area doubles the solar heat available. With the unglazed system, doubling the collector wall height may have no impact on solar heat available; solar heat at lower portions of the wall may be lost to the wind or radiated to the sky. Second, the unglazed

collector was tested at the National Solar Test Facility for two flow rates and three wind speeds. Both flow rates, however, were significantly higher than the flows measured at McDonnell-Douglas. Using the NSTF data requires a large extrapolation of the test data, which introduces errors in the analysis.

Despite these problems the SIMAIR computer program was run to see if the system is performing close to expectations. The SIMAIR program was modified to incorporate a wind dependent collector efficiency curve:

$E =$ Frta (no wind) - Frb.W_a.WSAF

Frta is the collector efficiency when there is no wind (=0.38)

where Frb is the reduction in Frta due to wind in 5/m

W_a is the airport wind speed in m/s

WSAF is the wind speed augmentation factor

The Frta and Frb terms were determined from NSTF results on a test sample similar to the McDonnell-Douglas Solarwall. The test numbers were reduced by 10% to account for the lower absorptivity of the dark brown wall as opposed to the black wall that was tested. The wind speed augmentation factor is the ratio of the wind speed at the wall to the wind speed reassured at the airport. A ratio of 0.4 was used based on the results given in Section 3.1.

Figure 3.9 shows the computer simulated and monitored performance of the Solarwall. The simulations were performed with two different collector areas: the full collector area (2677 m^2) and that portion of the wall serviced by the air handling system (1606 m^2). Toronto TMX (typical meteorological year) weather data was used because a full year of site-measured data was not available. The simulated values for January and February are within the range of uncertainty in the monitored data. The predicted annual solar energy delivered is estimated to be between 838 and 1040 GJ or 0.39 GJ/m^2 based on the area serviced by the air handling system. Excluding the summer, the solar heat collection efficiency was simulated to be between 13.5 and 18.2%. The annual reduction in heating load due to destratification was calculated to be 4900 GJ based on a continuous exhaust of 47.6 m^3/s (100,000 CFM).

Solar Energy Collected
(Simulated and Monitored)

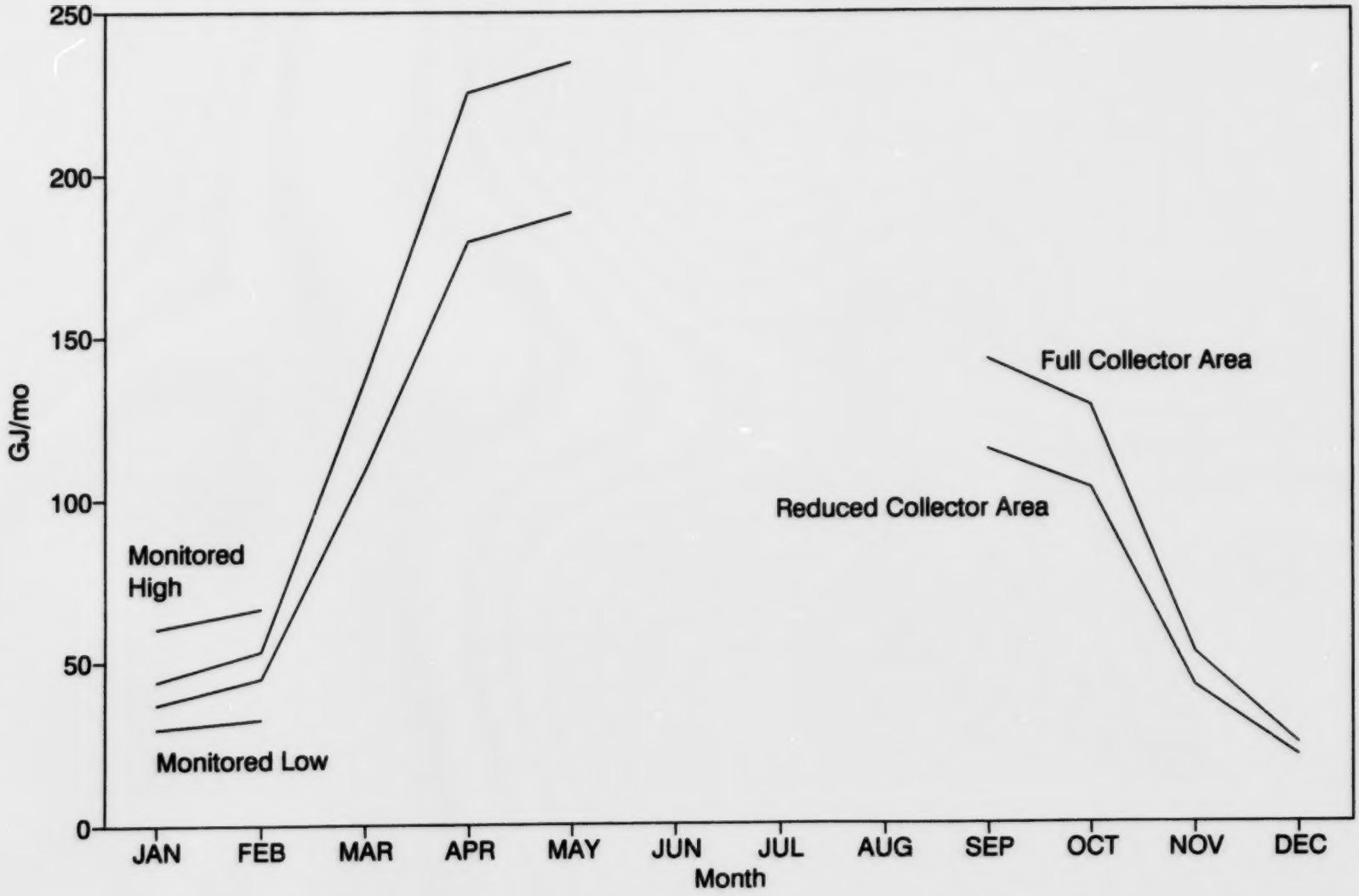


Figure 3.9

3.5 Infra-red Thermography

Infra-red thermography was used in an attempt to gain a better understanding of the air flow patterns over the Solarwall. It was reasoned that there should be a temperature gradient up the wall with the hottest areas at the top of the wall. Any flow dead spots would show up as hot spots. Figure 3.9 shows an infra-red photograph of the section of Solarwall shown in Figure 3.10 on a calm sunny day. The photograph shows no vertical temperature gradient. The only temperature variations are due to the thermal bridging of the metal support structure. The sun shadow of the bypass hood can be seen as the cold dark spot at the top of the photograph. The lack of vertical temperature gradient indicates either poor coupling between the air and the wall or that the vertical boundary is separating from the wall.

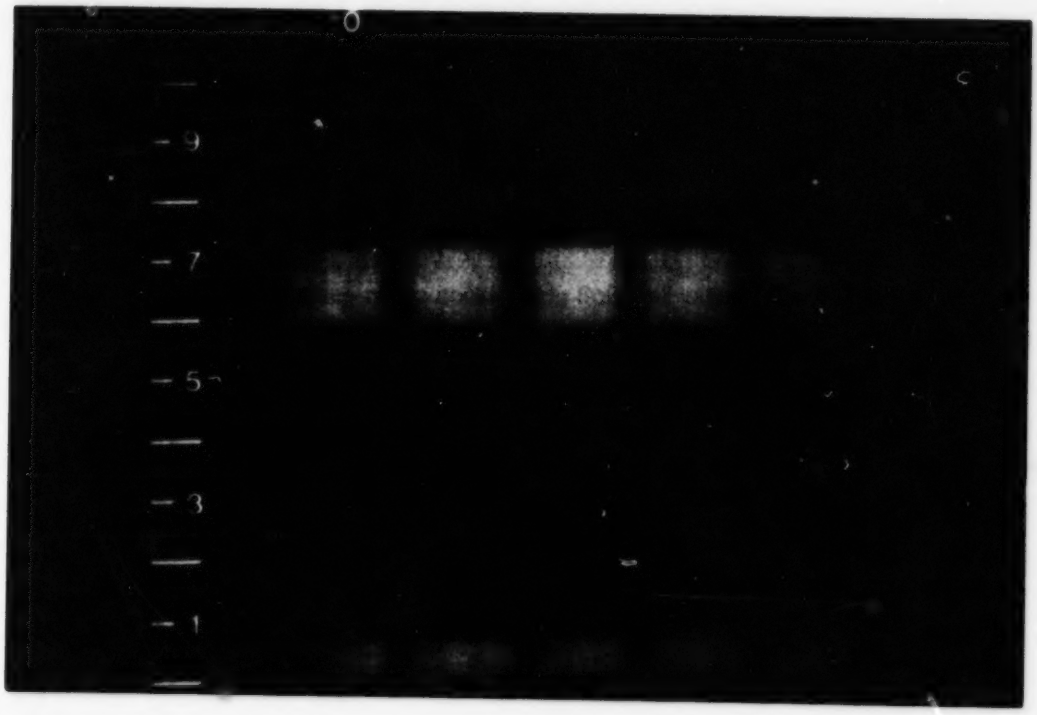


Figure 3.10 Infra-red photograph of McDonnell-Douglas Solarwall

Figure 3.11 Photograph of same section of Solarwall as in Figure 3.10

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The wind speed at the surface of the south-facing Solarwall is less than half of that measured on the roof (which, in turn, is typical of airport wind speed measurements). The long flat side of the building causes the wind to blow almost always parallel to the Solarwall.

Ambient air at the south side of the building is, on average, two Celsius degrees warmer than air on the roof at night and as high as 3.5 Celsius degrees during the day.

A significant portion (between 6 and 12 percent during the day and 20 to 25 percent at the night) of the air entering the Solarwall inlet plenums comes from air leakage at the top the building. The air leakage is caused by pressurizing the building and cracks in the building shell at the hangar door/roof interface. This leakage, which is not typical of most buildings, made it difficult to analyze the data.

On average, each day in January and February, the Solarwall supplied between 1132 and 1433 kWhrs of energy of which 610 kWhrs was from high south side ambient temperature, 233 kWhrs from reduced wall heat loss and between 289 and 590 kWhrs from heating of inlet air. Further energy savings came from reducing the temperature stratification by 3 Celsius degrees. The solar energy heat collection efficiency, based on daytime air heating and reduced wall loss, is between 8.9 and 11.6%.

Computer simulation was used to project annual energy savings of between 838 and 1040 GJ for solar heat collection and 4900 GJ for destratification. Collector efficiency was calculated to be between 13.5 and 18.1%.

4.2 Recommendations

The following recommendations are made:

- future Solarwalls should be constructed to minimize any building air leakage near the ventilation air inlet plenums;
- a more representative Solarwall system should be monitored for the 1990-91 heating system (i.e., one that does not have air leakage problems);
- an unglazed collector model, based on fundamental heat and mass transfer, should be developed. The results of this model should be incorporated into the SIMAIR computer program;

5. REFERENCES

McClenahan, D. and S. Carpenter, "Solar Preheating of Ventilation Air at the Ford Oakville Plant", paper presented at 15th Annual S.E.S.C.I. Conference, Penticton, B.C., June 1989.